Faculty of Engineering

SMALL SIGNAL STABILITY OF A POWER SYSTEM WITH HIGH PENETRATION OF SOLAR ENERGY

CHE WAN NOR FITTRY ELLINA BINTI CHE WAN MUDA

Bachelor of Engineering (Hons)

Electrical and Electronics Engineering

2019

UNIVERSITI MALAYSIA SARAWAK

Grade: A-

Please tick (√)

Final Year Project Report	☐
Masters	☐
PhD	☐

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CHE WAN NOR FITTRY ELLINA BINTI CHE WAN MUDA

A final year project report submitted in partial fulfilment of
the requirement for the degree of
Bachelor of Engineering (Hons) Electrical and Electronics Engineering

Faculty of Engineering
Universiti Malaysia Sarawak

2019

Dedicated to my beloved family, supervisor, lecturers and friends.

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I would like to thank the Faculty of Engineering for giving me a chance to work on this project and giving me experience on how to face problems and try to solve it.

ABSTRACT

The purpose of this project is to identify the effect of high penetration level of solar energy on small signal stability of a power system. With the growth of renewable energy development, the problems with high penetration level of renewable energy can no longer be ignored. The replacement of conventional generator with renewable energy generator has been taking placed in the power system generation as the non-renewable energy continue to deplete. Other than that, the final products excreted from non-renewable energy increased the pollution. With the level of penetration that currently exist, the small signal stability had no issues to be solved. The problem comes with high penetration level of solar. This was stated in terms of solar energy generation. Other than small signal stability, the issues will also come in terms of transient stability or large signal stability. The project focused on small signal stability as the previous studies showed conflicting results that need to be further investigated. A suitable power system had been chosen as a test system. The simulation was conducted by using two software which are Power World Simulator and MATLAB/Simulink. The analysis is based on characteristic system response. The penetration levels of solar energy were PV varied to see the characteristic response of the system. The high penetration level of solar may not have significant impact on small signal stability of power system based on the simulation.

ABSTRAK

Projek ini bertujuan untuk mengenal pasti kesan tahap penembusan tinggi tenaga suria terhadap kestabilan isyarat kecil sistem kuasa. Dengan pertumbuhan tenaga boleh diperbaharui, masalah pada tahap penembusan yang tinggi teenage boleh diperbaharui tidak lagi boleh diabaikan. Penggantian penjana konvensional dengan penjana tenaga boleh diperbaharui telah berlaku dalam penjanaan system tenaga kerana kuasa tidak boleh diperbaharui semakin berkurangan. Selain itu, pencemaran yang berlaku akibat rembesan gas daripada tenaga tidak boleh diperharui juga semakin meningkat. Dengan tahap penembusan yang kini wujud, kestabilan isyarat kecil tidak akan mempunyai masalah untuk diselesaikan. Masalah akan datang apabila tahap penembusan meningkat. Kenyataan ini dikaitkan dari segi tenaga suria. Selain kestabilan isyarat kecil, isu-isu ini juga akan dating dari segi kestabian isyarat besar. Projek ini hanya memberi tumpuan kepada isyarat kecil kerana kajian terdahuu menunjukkan hasil yang bercanggah yang perlu dilanjutkan siasatan. Sistem kuasa yang sesuai telah dipilih sebagai sistem ujian. Simulasi akan dijalankan dengan menggunakan dua perisian iaitu Power World Simulator dan MATLAB Simulink. Analisis ini berdasarkan analisis ciri-ciri tindak balas. Tahap penembusan tenaga solar akan berubah-ubah untuk melihat perubahan pada ciri- ciri tindak balas. Berdasarkan keputusan yang telah diperolehi daripada simulasi, tahap penembusan suria yang tinggi di dalam sistem kuasa mungkin tidak akan meninggalkan kesan yang teruk dari segi kestabilan isyarat kecil.

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DFIG	-	Doubly Fed Induction Generator
FACTS	-	Flexible Alternating Current Transmission Systems
G1	-	Generator 1
G2	-	Generator 2
G3	-	Generator 3
GENROU	-	Conventional Round Rotor Synchronous Machines
GHG	-	Greenhouse Gases
IEA	-	International Energy Agency
POI	-	Point of Interconnection
PSSs	-	Power System Stabilizers
PV	-	Photovoltaic
RHP	-	Right Hand Plane
STE	-	Solar Thermal Electricity
SVC	-	Static Var Compensator
TCSC	-	Thyristor Controlled Series Capacitor
USPVU	-	Utility Scale PV Unit
WEC	-	Wind Energy Converter
WECC	-	Western Electricity Coordinating Council

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, it is divided into seven subtopics. The first subtopic is project background where the background of the project is further elaborated. Next is renewable energy and stability of power system. Problem statement and the objectives of this project is also elaborated in this chapter followed by the scope of this project.

1.2 Project Background

Rising prime energy costs, technological advances and incentive programs have led to the replacement of conventional generators with photovoltaic (PV) generator [1] . Solar energy is widely used as it is an abundant source that never depleted. Solar energy is collected directly from the sun and semi-conductor solar cells and it is converted into electrical energy from light energy. It does not produce any greenhouse gases such as oil based energy does, nor any waste that need to be stored. Although the source is limited to time, solar energy requires no fuel or any moving part such as turbine that can produce noise pollution for the generation process compared to other renewable energy such as wind and hydroelectric power. The initial cost for the installation of PV panel is high but the maintenance and the repairing costs are very reasonable [2].

International Energy Agency (IEA) stated that, by 2050, solar thermal electricity (STE) could provide a further 11% from 'concentrating' solar power plants while Solar PV systems will be able to generate up to 16% of the world's electricity [3]. The top five countries that responsible for nearly 84% of newly installed PV capacity are China, United States, India, Japan and Turkey, followed by Germany, Australia, the Republic of Korea, United Kingdom and Brazil [4]. As mentioned before, one of the drawbacks of solar energy is it a time dependent source. California Independent System Operator published a chart in 2013 about solar photovoltaic large-scale deployment. The chart in Figure 1.1 shows the amount of solar energy available throughout the day and the difference in electricity demand. It is a snapshot during springtime of a 24-hour period in California [5].

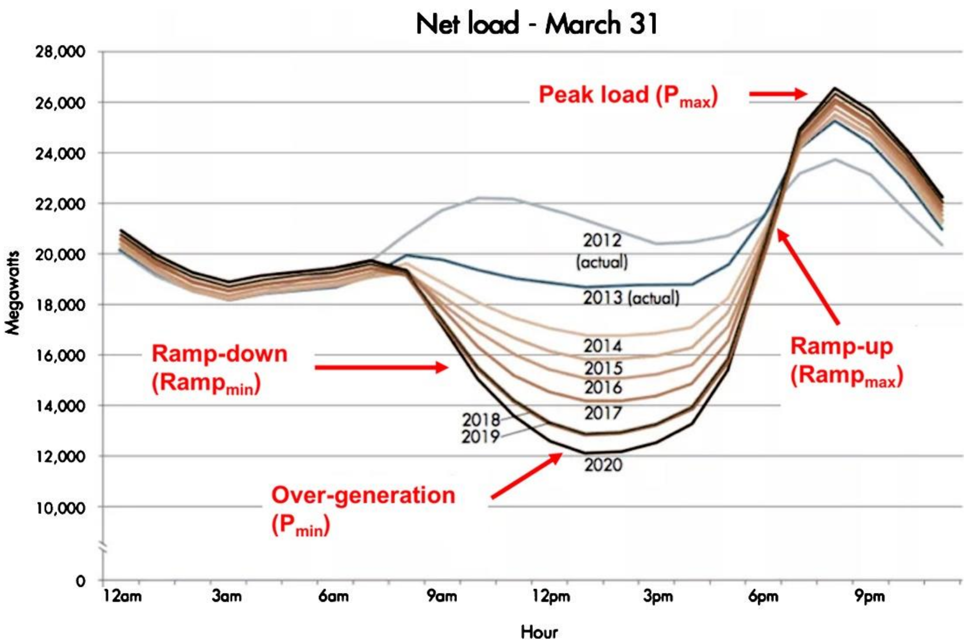

Figure 1.1: Duck curve of California [6].

The load is at its lowest during the day time. This is due to the fact that the temperature remained cool although it is sunny as people are not using air conditioning or heater during the day. This can be seen from the curve that the generation started to decrease or facing a ramp down from 8 a.m. to 7 p.m. When the sun set, the increased demand for electricity generator to quickly produce energy caused the contribution from PV to fall [5]. This situation creates a duck-shaped curve.

Due to the climate conditions in Malaysia, it is suitable for the solar energy development as throughout the year, Malaysia receive abundance of sunshine. Light winds, uniform temperature for being an equatorial country, high humidity and bountiful rainfall are the characteristic features of climate in Malaysia [7]. The annual average daily solar radiation received is estimated at 4.21kWh/m^2 to 5.56kWh/ m^2 [8].The generation potential of Solar PV in Malaysia is 275205.99 MWh, which is the highest generation compared to other renewable energy present in this country [5].

One of the factors for replacing the conventional energy with PV resources is the operating cost is high and the lifespan of conventional generator is shorter. The world is in need of special measures as there is an anomalous rapid changes to power grid in order to accommodate the needs of the future [9].

1.3 Renewable Energy

Renewable energy is generated using natural resources that are constantly replaced and does not depleted. The energy sources include geothermal, biomass, hydro, solar, tidal, and wind. In renewable energy, there are variable sources such as solar energy and wind energy. These sources are time and weather dependent. For example, the sunlight will be less intense if the weather is cloudy.

The existing power system is environmentally unfriendly as it tends to produce greenhouse gases (GHG) and it is inefficient. Reductions of carbon emission, technological innovations and climate change have been a great distress globally. The uses of energy, production and distribution, particularly traditional biomass and fossil fuels have major environmental impacts. Other than causing an ecological damage, it will also affect human's health. As a solution to lessen the negative effect of using non-renewable energy, the generation of energy using renewable resources is presented [7].

Global renewable generation capacity at the end of 2017 has mounted to 2179 GW. Figure 1.2 shows the renewable energy capacity. The mostly used renewable energy is hydro with 53% followed by wind energy with 23%. Solar energy is in the third place with 18% and the rest of renewable energy including biomass, geothermal, and tidal is 6% [10].

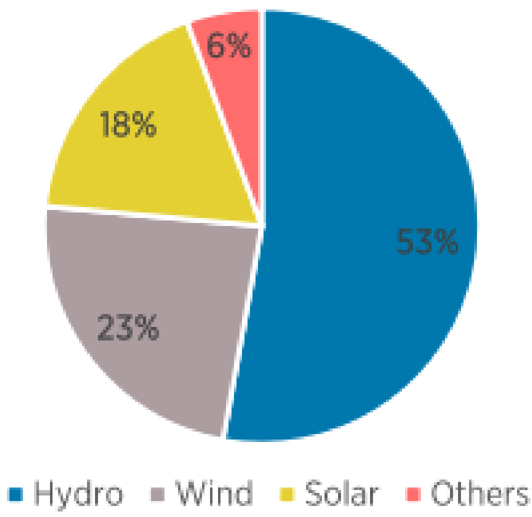

Figure 1.2: Renewable generation capacity [10].

Solar energy and wind energy installations accounted for 85% of all new capacity installed in 2017. It is mostly leading the expansion of renewable capacity [10].

1.4 Stability of Power System

Power system stability is the ability of the system, after being exposed to a physical disturbance, to regain a state of operating equilibrium for a given initial operating condition. The ability of the system to remain synchronised under small disturbance is the stability of small signal while transient stability is the ability of the system when it is subjected to a large disturbance to maintain the synchronism [11].

Stability of the power system has fundamental mathematical underpinnings. It is similar to any dynamic system stability. Power system operates in a constantly changing environment. The changes are coming from the key operating parameter, loads and the generator outputs. It is a highly nonlinear system. The stability of the system depended on the initial operating condition when there is a fault. It also depends on the nature of the disturbance [11].

Stability is divided into several categories. The first category is rotor angle stability. It refers to the ability of synchronous machines after being subjected to a disturbance, to remain in synchronism by restoring balance between mechanical torque and electromagnetic torque of each synchronous machines in the system. Instability problem comes from the increment of some generators' angular swings. Their synchronism with other generators will be lost. The stability of rotor angle is divided into small disturbance and transient or large disturbance. Both of these disturbances are categorised as a short term phenomena [11].

Frequency stability is also one of the categories in stability. It refers to the ability of the system after being subjected to a disturbance to maintain steady frequency. When the frequency is unstable, there will be a significant imbalance between load and generation. The tripping of generating units and load results from sustained frequency swings. It is one of the causes of the frequency instability. Frequency stability is divided into long term or short term phenomena [11].

The last category is voltage stability. It is the system's ability, after being subjected to a disturbance, to maintain steady voltages by restoring stability between load supply and load demand from the power system. At all buses in the system, the voltage must remain steady. Progressive rise or fall voltages of some buses results in the instability of voltages. Voltage stability is also subjected to large and small disturbance. Similar to frequency stability, it is also divided into long term and short term phenomena [11].

Figure 1.3 shows the classification of power system stability. It has been simplified to a diagram.

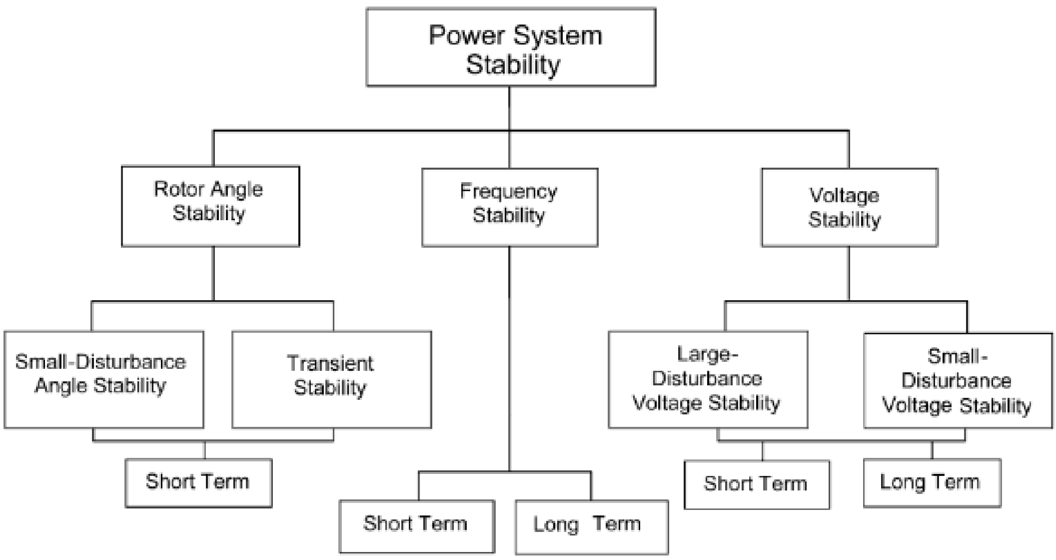

Figure 1.3: Classification of power system stability [11].

1.5 Problem Statement

The leading country for solar energy production is China. With the percentage of 2.294, solar energy is use to provide electricity in the country [12]. The stability of the system is not an issue when the penetration level is low. Most countries have low penetration level for solar energy. The effect on the stability of the system is less significant if the penetration level is low [13]. With the depletion of energy sources, the need for a clean energy is high. Solar energy is the only energy that does not require any moving parts and can easily be installed. Any changes made in power system will have an impact whether it is a good impact or bad impact. Studies with different aspects have been conducted to investigate the effect of high integration level of solar energy on the system with the expected increment of clean energy demand.

It is necessary for a reliable system operation to conduct the required task in an appropriate time in response to different disturbances. Previous studies have investigated the transmission system's transient behaviour responding to numerous disturbances associated to PV generation [9]. PV generation affecting transient voltages in both detrimental and beneficial ways depending on the point of interconnection (POI) and number of solar integration in the system [14].

The studies about PV generation at different penetration have been investigated from many aspects. Researchers from [15] investigated the impact of large generation of solar energy using real network data pertaining to Ontario, Canada based on eigenvalues, transient stability and voltage stability. Participation factor for increased solar PV penetration and load variation into the grid, damped frequency and damping ratio, are the aspects that is studied by researchers [8]. Other aspects also include characteristic of system on static performance and angle stability of penetrating PV generation into the grid. This work will be focusing on the influence of high PV integration on stability of small signal.